Progress Report 1999-2000

Title: **Remote Sensing and Understanding the Role of Cloud and Aerosol on Solar Radiation Budgets**

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1. SCIENTIFIC GOALS

The overall scientific goal of our investigation is to foster the use of ARM ground-based and airborne measurements together with space-borne observations from multiple platforms:

- *To advance our understanding the impact of cloud and aerosol on solar radiative transfer; and*
- *To develop aerial-mean radiation and cloud products in support of development and test of cloud-radiation parameterization and modeling studies.*

The first goal tackles with a key component of the first objective of the ARM, namely, "relate observed radiative fluxes and radiances …to … clouds and surface properties …". The second goal is closely related to the second ARM objective, namely, "develop and test parameterizations …".

In line with the first objective, we will address the following specific science issues:

1) *Do clouds absorb substantially more solar radiation than models predict? If so, what are the causes?*
2) *What are the effects of cloud structure and microphysics on the transfer of solar radiation and on the inference of radiation budget from satellite?*
3) *What are the effects of aerosol distribution and optical properties on the transfer of solar radiation and on the inference of radiation budget from satellite and how to account for them on a large scale?*

The realization of the second objective involves development, validation and application of several satellite-based remote sensing algorithms and products:

1) *Surface radiation budgets for total solar radiation, UV and VIS components.*
2) *Surface SW and spectral albedos*
3) *Cloud parameters essential to understanding cloud-radiation interaction*
4) *Solar radiative heating at various levels of the atmosphere*

2. ACCOMPLISHMENTS

- The impact of clear-sky variability on the determination of cloud radiative forcing (CRF) was investigated thoroughly. It was found that changes in aerosol, water vapor, surface albedo tend to cause an overestimation of surface CRF, but have relatively minor influence on TOA CRF, leading to an over-estimation of the ratio of CRF at the TOA over that at the surface. – **towards ARM's 1st Objective**.
- Developed new sets of angular dependence models (ADM) for converting satellite observed radiance to irradiance. The dependence of ADM on cloud properties and wavelength were investigated. Uncertainties resulting from the use of existing ADMs are quantified.

Improper angular correction was proven to be the largest source of uncertainties in deriving instantaneous TOA radiative fluxes. **– towards ARM's 2nd Objective**

- Conducted closure tests of solar radiative transfer using satellite and surface observations collected at the ARM and many other sites around the world. Cloud optical depths retrieved from ISCCP-DX are evaluated against ground-based retrievals. Much better agreements were found for DX data than for CX data. **– towards ARM's 1st Objective**
- Participation in ARESE-next experiment. During the ARESE-next campaign, many mobile measurements were taken of the surface spectral albedos over all major land cover types found in the regions, which are important to the interpretation of radiation measurements and remote sensing of cloud and radiation properties. **– towards ARM's 1st and 2nd Objective**
- Narrowband and broadband albedos are retrieved over a large domain in SGP from AVHRR, LANDSAT, CERES etc. A new method is proposed to estimate areal mean ground albedo from point measurements of downwelling irradiance. **– towards ARM's 2nd Objective**

3. PROGRESS AND RESULTS

(1) Quantifying uncertainties in determining SW cloud radiative forcing and cloud absorption due to variability in atmospheric background condition (Li and Trischenko 2000).

The concept of cloud radiative forcing (CRF) has been widely employed in studying the effects of clouds on the earth's radiation budget and climate. CRF denotes, in principle, the net influence of cloud alone on the radiation budget of a system. In practice, however, observational determination of CRF is fraught with uncertainties due to factors other than cloud that induce changes in atmospheric background conditions. The most notable variables include aerosol, water vapor, and data sampling scheme. The impact of these factors on the derivation of CRF and cloud absorption is investigated by means of modeling and analysis of multiple data sets. Improved estimation of CRF is attempted at the top of the atmosphere (TOA) and at the surface from spatially and temporally co-located ground and satellite measurements for broadband (BB) shortwave (SW) fluxes made around the world. It is found that surface CRF is much more susceptible to the variability in background conditions than TOA CRF. Selection of overly clear-sky conditions often leads to significant overestimation of surface CRF, but TOA CRF remains intact or only slightly affected. As a result, the ratio of CRF at the surface and TOA is prone to overestimation. With careful treatments of these effects, the CRF ratio turns out to vary mostly between 0.9 to 1.1, implying approximately the same magnitude of atmospheric absorption under clear-sky and cloudy-sky conditions.

(2) **Development of new sets of angular dependence models (ADM) and study their variations with cloud optical properties and wavelength (Chang et al. 2000a, 2000b; Pubu and Li 2000).**

ADM is the largest source of uncertainties in deriving instantaneous solar radiative fluxes at the top of the atmosphere (TOA). The quality of the TOA radiation budget products depend critically on how accurate is the conversion from radiance to irradiance. This team has conducted extensive studies to better understand the ADM and to develop improved ADM models. Chang et al. (2000a) examined the relationship between TOA radiance and irradiance data from ERBE with those computed according to the cloud properties from AVHRR data. Good agreements were found for radiance, but poor for irradiance. The discrepancies were found to originate from the use of the ERBE/ADM that lacks a dependence on cloud optical properties, an important finding in understanding the relationship between cloud and radiative quantities using satellite data. To partially remedy the problem, Chang et al. (2000b) developed a new set of ADMs for some broad categories of cloud scenes (thin/thick, water/ice and all clouds) using ScaRaB data. Different ADMs were also developed for visible and broadband spectral regions. Pubu and Li (2000) studied, for the first time, the behavior of ADM for UV radiation and found that they differ considerably from the visible and broadband ADMs. They developed complete sets of ADMs for several UV regions using the TOMS satellite data.

(3) Comparison of cloud optical depths and radiative flux between satellite and surface retrievals from multiple platforms (Trishchenko et al. 2000)

The performance of cloud and radiation retrieval schemes was assessed by comparing the results of retrievals from ground and satellite measurements. Two parameters were analyzed: cloud optical depth in the visible band and broadband shortwave (SW) albedo at the top-of-the-atmosphere (TOA). Comparisons of cloud optical depths retrieved from ground measurements with those from ISCCP DX data revealed significant improvements over the original ISCCP CX data. Similar good agreements were obtained between retrieved and measured TOA SW albedo. Differences appear to fall within the uncertainties in surface albedo, cloud layer structure, vertical profiles of the atmospheric absorbers such as water vapor and aerosol, as well as the deficiencies in plane-parallel radiative transfer model and in the inversion schemes. Such closure tests safeguard the use of various cloud and radiation data sets under study in developing and testing cloud-radiation parameterization schemes.

(4) Retrieval of surface spectral and broadband albedos from satellite and ground-based observations around the SGP region (Li et al. 2000, in preparation)

Surface spectral albedo is a fundamental variable affecting the transfer of solar radiation and is a basic model input parameter. Over the ARM/SGP site, the spatial non-uniformity and temporal variability of the surface pose a significant problem for both remote sensing and modelling studies. Our investigation found that the ground-based surface albedo measurements made at the central facility differ significantly from the aerial mean values that are required by both models and satellite retrievals. Three approaches were proposed to tackle this problem. First, spectral surface albedos were derived from a limited number of satellite channels such as NOAA/AVHRR, and LANDSAT TM over the course of a year. Second, a novel approach was proposed to derive aerial mean spectral albedos of high spectral resolution using ground-based measurements of downward irradiance made by such spectrometers as RSS under overcast conditions. The third approach is to combine ground-based observations of spectral albedo with a mobile spectrometer made over major land cover types found in the region with land cover maps obtained by ground survey, satellite-based classifications. Following the three approaches, a comprehensive surface albedo data base are being generated in support of remote sensing and modelling studies.

4. **Refereed Journal Publications**

Li, Z., and A. Trishchenko, 2000: Quantifying the uncertainties in determining SW cloud radiative forcing and cloud absorption due to variability in atmospheric background condition, *J. Atmos. Sci.*, in press.

Li, Z., A. Trishchenko, H. W. Barker, G. L. Stephens, and P. T. Partain, 1999: Analysis of Atmospheric Radiation Measurement (ARM) Program's Enhanced Shortwave Experiment (ARESE) multiple data sets for studying cloud absorption, *J. Geophy. Res.* 104, 19,127-19,134.

Chang, F.-L., Z. Li, and A. Trishchenko, 2000: The dependence of TOA anisotropic reflection on cloud properties inferred from ScaRaB satellite data, *J. Appl. Meteor.*, in press.

Chang, F.-L., Z. Li, and S. A. Ackerman, 2000: Examining the relationship between cloud and radiation quantities derived from satellite observations and model calculations, *J. Climate*, in press.

Ciren, P., and Z. Li, 2000: The TOA Anisotropic Reflection of UV Radiation, Characteristics and Models Obtained from Meteor-3/TOMS, *J. Geophy. Res.*, accepted with revision.

Trishchenko, A., Z. Li, F.-L. Chang, and H. Barker, 2000: Cloud optical depths and TOA fluxes: Comparison between satellite and surface retrievals from multiple Platforms, submitted.

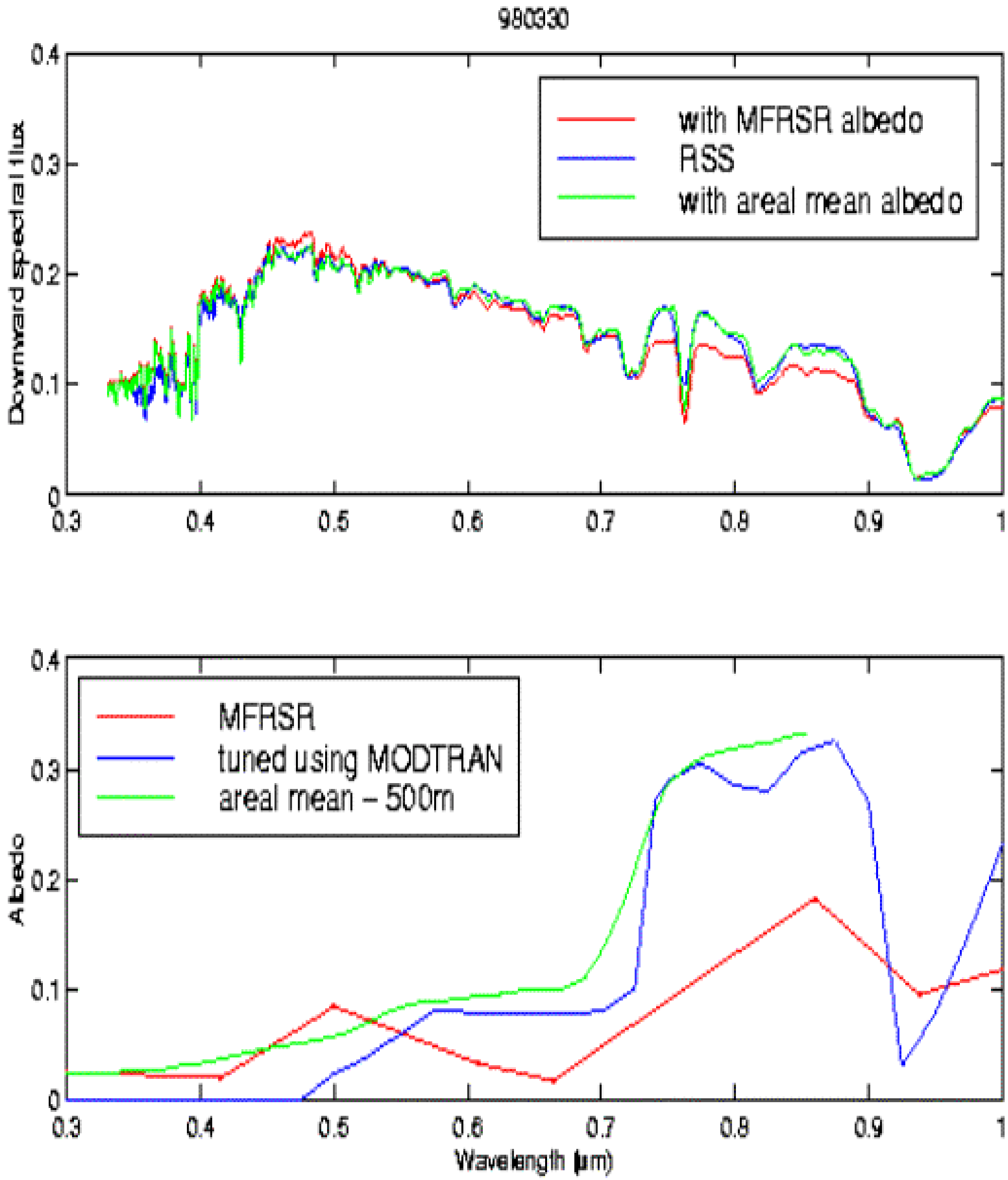

Figure 1. This figure is concerned with a closure test of solar radiative transfer on an overcast day. It underlines the importance to have a good knowledge in surface spectral albedo accurately and demonstrates a means of deriving it from DOWNWELLING spectral irradiance observations under overcast conditions.

Further discussion of Fig. 1

The upper one shows a comparison of spectral transmittance observed by RSS and computed by a model with cloud input parameters derived from various ground-based instruments. Three spectral fluxes are compared: RSS observations, modeled values with MFRSR observed albedo at the central facility, modeled values with aerial mean spectral albedos observed over a large area. The comparison suggests that a closure may not be achieved without a good knowledge on surface albedo. We are striving to obtain sufficiently reliable surface spectral albedo over the SGP site to support various ARM investigations.

The lower panel shows a comparison of surface spectral albedos observed by MFRSR at the central facility, aerial mean albedos derived from measurements over typical land cover types in combination with land cover classification around the CF, and albedos inferred from the comparison of transmittance by tuning surface albedo so that the observed and modeled transmittances are identical. The good agreement between observed aerial mean albedos and those inferred from transmittance measurements comparison indicates that one can estimate aerial mean albedo from downwelling irradiance observations made under overcast conditions, provided cloud properties are known from other sources.

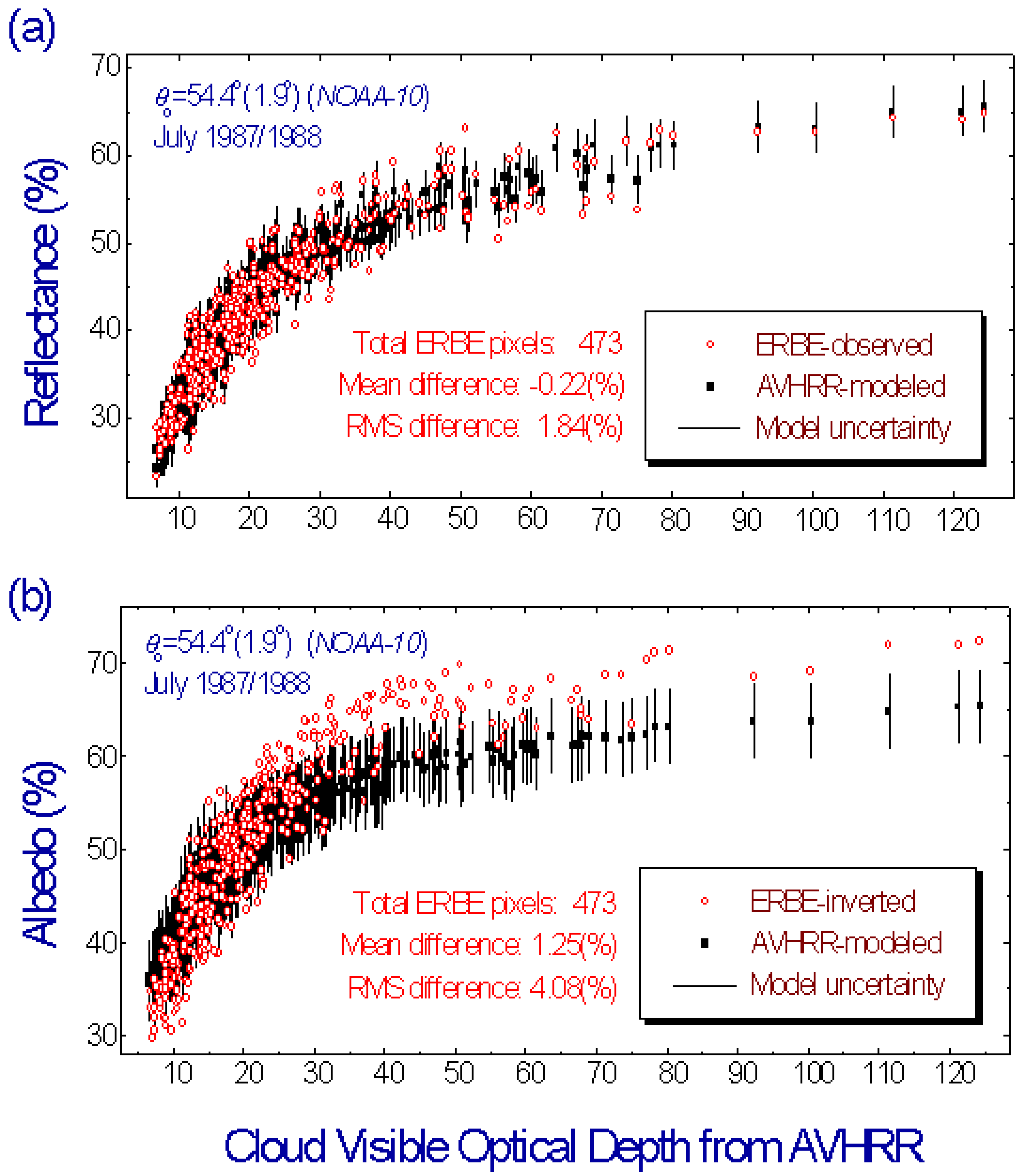

Figure 2. Comparisons of the relationship between both shortwave (SW) top-of-atmosphere (TOA) reflectance and albedo and cloud optical properties. (To appear in *J. Climate*)

Further discussion of Fig. 2

The broadband radiative quantities were taken from the Earth Radiation Budget Experiment (ERBE), while cloud optical properties were derived from narrowband measurements from the Advanced Very High Resolution Radiometer (AVHRR) satellite mission. The comparisons are for low-level, single-layered, maritime stratus clouds with uniform cloud tops. Cloud optical depth, droplet effective radius, and top temperature were retrieved from AVHRR 0.63, 3.7, and 11-μm spectral measurements. A radiation model was then applied to the retrieved cloud optical properties to compute SW TOA overcast reflectances and albedos that are compared to the coincident ERBE observations. The bars denote the maximum ranges of uncertainties in the model calculations.

The comparison of reflectances shows excellent agreement in terms of both trend and magnitude. Yet, the differences between the two reflectances display no dependence on any of the physical parameters. Since no inversion algorithm was involved in obtaining the ERBE reflectance data, the good agreement bolsters our confidence on the fundamentals of solar radiative transfer in such ideal cloudy conditions. On the other hand, the comparison between two albedos exhibits significant differences that have a strong dependence on cloud optical depth. The discrepancies are found to originate from the use of a single ERBE/ADM in converting SW reflectances to albedos for all overcast scenes, regardless of their cloud optical properties. The resulting uncertainties in instantaneous pixel fluxes may reach up to 40-50 W/m^2 for persistent large or small cloud optical depths, while the problem is relieved considerably in deriving regional or monthly mean fluxes.

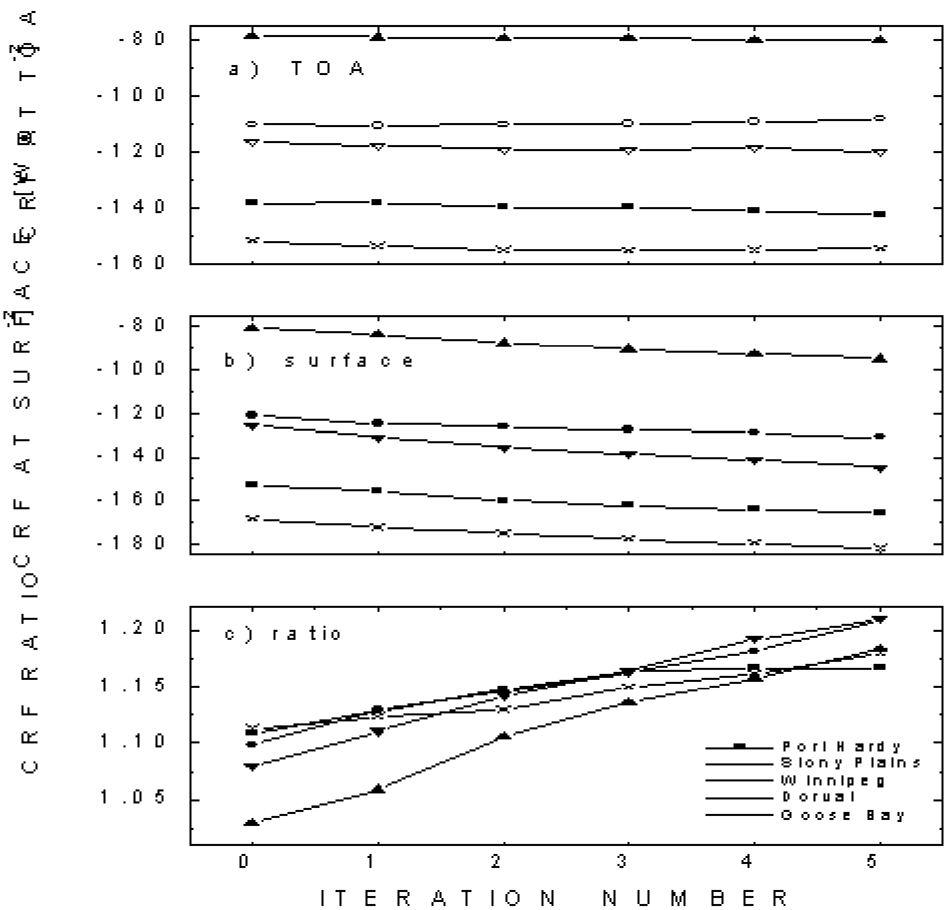

Figure 3. Sensitivities of TOA and surface cloud radiative forcing (CRF), as well as their ratio, to the selection of clear-sky scenes. As the number of iteration increases, the clear skies become increasingly clean and dry, but less representative of all sky condition. While this has a relatively minor effect on TOA CRF due to offsetting effects, it tends to overestimate the magnitude of CRF at surface. As a result, their ratio is prone to overestimation if overly clear scenes were selected. (To appear in *J. Atmos. Sci*.)